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SECOND-ORDER SCHEDULES OF TOKEN REINFORCEMENT WITH PIGEONS: EFFECTS OF FIXED- AND VARIABLE-RATIO EXCHANGE SCHEDULES

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Pigeons' key pecks produced food under second-order schedules of token reinforcement, with light-emitting diodes serving as token reinforcers. In Experiment 1, tokens were earned according to a fixed-ratio 50 schedule and were exchanged for food according to either fixed-ratio or variable-ratio exchange schedules, with schedule type varied across conditions. In Experiment 2, schedule type was varied within sessions using a multiple schedule. In one component, tokens were earned according to a fixed-ratio 50 schedule and exchanged according to a variable-ratio schedule. In the other component, tokens were earned according to a variable-ratio 50 schedule and exchanged according to a fixed-ratio schedule. In both experiments, the number of responses per exchange was varied parametrically across conditions, ranging from 50 to 400 responses. Response rates decreased systematically with increases in the fixed-ratio exchange schedules, but were much less affected by changes in the variable-ratio exchange schedules. Response rates were consistently higher under variable-ratio exchange schedules than under comparable fixed-ratio exchange schedules, especially at higher exchange ratios. These response-rate differences were due both to greater pre-ratio pausing and to lower local rates under the fixed-ratio exchange schedules. Local response rates increased with proximity to food under the higher fixed-ratio exchange schedules, indicative of discriminative control by the tokens.

Key words: fixed-ratio schedules, variable-ratio schedules, second-order schedules, token reinforcement, behavioral units, key peck, pigeons

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That behavior can be established and maintained by schedules of token reinforcement has long been recognized. Token-reinforcement procedures have been used successfully in applied settings for many years (Kazdin, 1977). In the laboratory, token-reinforcement procedures have been used to generate extended sequences of behavior in a variety of species, including dogs (Ellson, 1937), cats (Smith, 1939), chimpanzees (Cowles, 1937; Kelleher, 1956, 1957a, 1957b, 1958; Wolfe, 1936), and rats (Boakes, Poli, Lockwood, & Goodall, 1978; Malagodi, 1967a, 1967b, 1967c, 1967d; Midgley, Lea, & Kirby, 1989).

Under token-reinforcement procedures, responses produce tokens according to one schedule (the token-production schedule) and opportunities to exchange those tokens for other reinforcers according to a second schedule (the exchange schedule). Token-reinforcement schedules have been conceptualized as second-order schedules (Kelleher, 1966) in which responding engendered by the token-production schedule is treated as a unitary response that produces reinforcement according to the exchange schedule. As with other types of second-order schedules (Gollub, 1977; Marr, 1979), rates and patterns of behavior under token-reinforcement schedules are jointly determined by the first-order token-production schedule and the second-order exchange schedule (Kelleher, 1957b; Webbe & Malagodi, 1978).

Evidence of control by the token-production schedule comes from studies showing that response patterns obtained under a variety of schedules of token production resemble those obtained under schedules of primary reinforcement (Kelleher, 1956, 1957a, 1957b, 1958; Malagodi, 1967a, 1967b, 1967c, 1967d). For example, in a study by Kelleher (1958), chimpanzees' lever presses produced

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poker chips according to a fixed-ratio (FR) 30 schedule (every 30 responses produced a poker chip), with exchange periods scheduled after 50 tokens had been obtained. As with simple FR schedules of food reinforcement, bivalued response patterns emerged under the FR token-production schedule: Responding occurred at a high steady rate, with short pauses prior to each ratio run. In later conditions, when the token-production schedule was increased from 60 to 125, overall response rates decreased and preratio pausing increased, an effect similar to that seen with FR schedules of food reinforcement (Felton & Lyon, 1966; Mazur, 1983).

The clearest evidence of sensitivity to the exchange schedule comes from experiments in which manipulations of exchange-schedule variables produce schedule-typical rates and patterns (Kelleher, 1957b; Waddell, Leander, Webbe, & Malagodi, 1972; Webbe & Malagodi, 1978). In a study by Webbe and Malagodi, rats' lever presses produced marbles according to an FR 20 schedule and exchange periods according to either FR 6 or variable-ratio (VR) 6 schedules. That is, exchange periods were scheduled when either exactly six tokens (FR) or an average of six tokens (VR) had been earned. Response rates were consistently higher under the VR exchange schedule than under the FR exchange schedule, an effect due primarily to greater preratio pausing under the FR exchange schedule.

The attenuation of pausing under the VR exchange schedule was likely due to the occasional smaller exchange requirements, just as on simple VR schedules (Ferster & Skinner, 1957). Indeed, Webbe and Malagodi (1978) suggested that the relation between the FR token-production schedule and FR and VR exchange schedules was comparable to that of individual responses and simple FR and VR schedules, supporting a second-order interpretation. By this view, the entire FR token-production sequence serves as a unitary response with respect to the second-order exchange schedule.

The present study sought to examine the generality of these exchange-schedule effects across a wider range of schedule conditions, including parametric manipulation of exchange-schedule value. Detailed parametric information bears critically on the unitary properties of token-reinforced behavior. If the relation between token-production units and exchanges follows the pattern typical of individual responses and simple schedules, then the differences in the rate and patterning under VR and FR schedules should increase with exchange ratio as they do under simple ratio schedules (Mazur, 1983).

The present study also extended the token-reinforcement preparation to a different species (pigeons) and to a different form of token reinforcement (a bank of light-emitting diodes, or LEDs). Previous studies of token-reinforced behavior with nonhumans have used as tokens small, physically manipulable objects such as balls (dogs, cats), poker chips (chimpanzees), or marbles (rats). Indeed, Gollub (1977) defined tokens in terms of their physical properties, but others have defined tokens more generically, as conditioned reinforcers that one may accumulate and later exchange for other reinforcers (e.g., Catania, 1998; Winkler, 1980). This latter definition would include nonmanipulable objects and stimuli such as lights and points exchangeable for money.

The rationale for substituting nonmanipulable visual stimuli for manipulable stimuli comes from evidence that token manipulation can attenuate schedule control during the token-production or exchange sequence (Boakes et al., 1978; Breland & Breland, 1961; Malagodi, 1967c; Midgley et al., 1989). For example, Boakes et al. found that rats engaged in token-directed consummatory-like responses (chewing, licking), even when such behavior resulted in increased delays to the primary reinforcers for which the tokens were exchangeable (see also Breland & Breland). The authors concluded that token-directed behavior arose from stimulus–reinforcer relations embedded within the token-reinforcement schedule (the token–food pairings arranged during exchange periods), and that such behavior competed with behavior maintained by response–reinforcer relations (the contingency between deposits and food).

Such interactions between stimulus–reinforcer and response–reinforcer relations in token-reinforcement procedures raise interesting questions for further study. At the same time, it may be desirable to explore alternatives to manipulable tokens that are less susceptible to intrusions from stimulus–reinforcer relations. To that end, the present experiments utilized a preparation developed by Jackson and Hackenberg (1996) based on illumination of LEDs as a form of token reinforcement. In this arrangement, LEDs are arrayed horizontally above the response keys. Pecks on a side key illuminate LEDs from left to right. During scheduled exchange periods, each peck on the center key extinguishes one LED and raises the food hopper. Thus, LEDs earned by pecks on the token-production schedule are exchanged for food according to the exchange schedule.

Jackson and Hackenberg (1996) examined pigeons' choices between different numbers of and delays to LEDs in a discrete-trial procedure, and varied the ratio of trials to exchange periods across conditions from 1:1 (exchange period every trial) to 10:1 (exchange period every 10th trial). In conditions with intermittent exchange periods, later trials began in the presence of LEDs earned on previous trials. Latencies were substantially longer on the first trial of the block (prior to any token deliveries) than on subsequent trials (with at least some tokens present), consistent with preratio pause effects seen in token-reinforcement schedules and other extended-sequence and chained schedules (Gollub, 1977; Kelleher, 1966).

The present study investigated whether, and to what extent, similar schedule-related effects would be seen in more conventional second-order schedule arrangements. In Experiment 1, both exchange ratio size and ratio type (FR vs. VR) varied across conditions. The token-production schedule was held constant at FR 50 while the exchange schedule was varied across conditions from 1 to 8, such that between 50 and 400 responses were required per exchange. In Experiment 2, the token-production schedule and the exchange schedule were varied separately and together across conditions. In some conditions, a VR token-production schedule operated with an FR exchange schedule. In other conditions, an FR token-production schedule operated with a VR exchange schedule. The number of responses per token, per exchange, and per food reinforcer was held constant across exchange-schedule types and values. Together, these experiments permit an examination of exchange-schedule effects when both a fixed and a variable number of responses are required to produce and exchange tokens. Detailed parametric information on the functions relating response rate and patterning to FR and VR exchange value will clarify the relation between token-reinforcement schedules and both simple schedules and other types of second-order schedules. The results will also shed light on the functional comparability of manipulable and nonmanipulable token stimuli, and the degree to which token handling is a necessary component of token-reinforcement schedules.

EXPERIMENT 1

METHOD

Subjects

Three adult male White Carneau pigeons served as subjects. Each was naive with respect to the present procedures, although one (1855) had prior experience with token-reinforcement procedures. The pigeons were individually housed in a temperature- and humidity-controlled vivarium (lights on from 7:30 a.m. to 11:00 p.m.) with continuous access to water and grit. The pigeons were maintained at approximately 80% of their free-feeding weights via supplemental feeding.

Apparatus

One Lehigh Valley Electronics operant chamber for pigeons, measuring 52 cm long, 36 cm wide, and 36 cm high, served as the experimental space. The modified control panel contained three horizontally-aligned plastic response keys, each 2.5 cm in diameter. The keys, located 9 cm below the chamber ceiling, required a force of approximately 0.23 N to operate. Each key could be transilluminated yellow, red, or green. A 7-W houselight, located 6 cm above the center response key, provided general illumination. Primary reinforcement consisted of 2-s access to mixed grain delivered by a solenoid-operated food hopper. The hopper aperture, centrally located in the bottom third of the control panel 11 cm below the center key and 9 cm above the floor grating, contained a magazine light and a Med Associates photocell apparatus that allowed precise timing of hopper access. Thirty evenly spaced, red LEDs served as tokens. (Hereafter, for ease of exposition, the LEDs will be referred to as tokens.) Tokens were arranged in a horizontal row 4 cm above the response keys and protruded 0.3 cm into the chamber. Tokens were presented and withdrawn through operation of an electromechanical stepping switch (Lehigh Valley Electronics, Model 1427), mounted on the outside top of the chamber enclosure. Tokens were always presented from left to right and withdrawn from right to left. Token onset and offset were accompanied by auditory feedback from the stepping switch. The chamber was housed within a ventilated, sound-attenuating shell. A white noise generator provided additional masking noise. Experimental contingencies were controlled by Med-PC® (Version 2) software on an IBM PC®-compatible computer located in an adjacent room.

Procedure

Token-production and exchange training. Following 2 days of adaptation to the chamber with the houselight (Session 1) and houselight and tokens (Session 2) illuminated, each pigeon was exposed to several sessions of magazine training. These sessions began with all 30 tokens illuminated. At irregular intervals (every 30 s, on average) the rightmost token was turned off and the food hopper was raised until the pigeon received 2-s access to food (timed from entry of head into food hopper). Once a pigeon ate reliably from the food hopper, pecks to the center (red) key were shaped by reinforcing successive approximations with food. When responses on this center (exchange) key were established, the pigeon spent one session during which the exchange key was made available at irregular intervals throughout the session. With all 30 tokens illuminated, a single peck on the exchange key turned it dark, offset the rightmost token, and raised the food hopper, providing 2-s access to grain. Sessions ended when all 30 tokens had been exchanged.

Once token exchange had been established, token-production training was conducted. Pigeons were placed into the chamber with all tokens off. Responses on the right (yellow) side key were shaped using the illumination of a token as a consequence. Token presentation was accompanied by a 0.01-s flash of the houselight and keylight, and was followed immediately by an exchange period, signaled by the onset of the red center key. As before, a single peck on this exchange key turned off one token and produced 2-s access to food. (In subsequent conditions in which multiple tokens accumulated prior to exchange, the exchange key remained illuminated until all tokens had been exchanged for food.) The token-production key darkened during exchange periods, and was reilluminated following the food delivery.

When token production and exchange occurred reliably, the schedule by which tokens were produced (hereafter, the token-production schedule) was gradually increased to FR 50, where it remained for the duration of the experiment. The entire sequence of conditions comprising token-production and exchange training required approximately 14 1-hr sessions.

Experimental procedure. The number of tokens required to produce the exchange period (hereafter, the exchange ratio) and the type of exchange schedule (FR or VR) was varied systematically across conditions. Pigeons were first exposed to an ascending sequence of FR exchange schedules (FR 1, FR 2, FR 4, and FR 8) and then to a descending sequence in which FR exchange schedules were interspersed with VR exchange schedules having the same mean value (VR 8, FR 4, VR 4, FR 2, VR 2, and FR 1). Experimental conditions were in effect for at least 20 sessions; stability was assessed via visual inspection of overall response rates per session. Conditions were changed when overall response rates failed to show evidence of monotonic trend or bounce. Table 1 presents the sequence of conditions and the number of sessions per condition for each pigeon.

Throughout the experiment, the ratio between overall number of token-production responses and overall amount of access to the food hopper was held constant at 2,400 responses for 96 s of access (48 exchanges) per session. This constancy was maintained by manipulating the number of exchange cycles presented per session. For example, the FR 2, FR 4, and FR 8 conditions arranged for sessions to end after 24, 12, and 6 exchange cycles, respectively. Unlike the FR exchange conditions, the number of tokens required to produce the exchange period varied from one exchange cycle to the next under the VR

Table 1

Experiment 1. The sequence of conditions (exchange-schedule values are noted) and the number of sessions (in parentheses) conducted under each condition.

Pigeon 10732	Pigeon 1855	Pigeon 5560
FR 1 (24)	FR 1 (23)	FR 1 (76)
FR 2 (144)	FR 2 (49)	FR 2 (21)
FR 4 (152)	FR 4 (106)	FR 4 (105)
FR 8 (54)	FR 8 (126)	FR 8 (38)
VR 8 (26)	VR 8 (28)	VR 8 (65)
FR 4 (24)	FR 4 (43)	FR 4 (39)
VR 4 (57)	VR 4 (40)	VR 4 (39)
FR 2 (37)	FR 2 (27)	FR 2 (27)
VR 2 (33)	VR 2 (50)	FR 1 (23)
FR 1 (41)	FR 1 (40)	

exchange conditions. These values were drawn, without replacement, from a rectangular distribution ranging from 1 to $2n - 1$, where n equals the average number of tokens required to produce an exchange period. Thus, the range of possible values for the VR 2, VR 4, and VR 8 exchange schedules were 1 to 3, 1 to 7, and 1 to 15, respectively. The ratio of number of responses and seconds of access to food was maintained at the values described earlier by forcing the last element in the list to make up the difference. This had the effect of slightly but unsystematically altering the obtained VR schedule value.

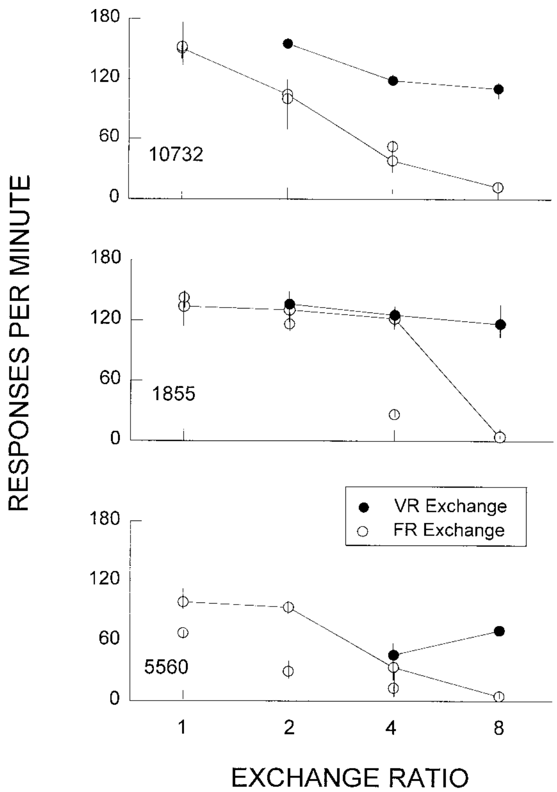

Fig. 1. Mean number of responses per minute as a function of FR (open symbols) and VR (filled symbols) exchange ratio. Connected points represent data from original exposures, and unconnected points represent data from second exposures. Error bars indicate the range of values contributing to the condition mean.

Results

All results are based on the final five sessions of each condition. Figure 1 shows overall response rates as a function of exchange ratio and schedule type (FR or VR) for each pigeon. Response rates declined systematically as a function of FR exchange ratio, but were not systematically affected by the VR exchange ratio. Within a given exchange ratio, VR exchange schedules produced consistently higher response rates than comparable FR exchange schedules, especially at the higher exchange ratios. At the highest exchange ratio of 8, responding under VR exchange schedules was well maintained (70 to 120 responses per minute, across pigeons) but was only weakly maintained under FR schedules (less than one response per minute), despite the same average number of responses per exchange (400). With two exceptions (FR 2 exchange for Pigeon 5560 and FR 4 exchange for Pigeon 1855), response rates under replicated conditions were in good accord with those from original conditions. In both of these exceptions, rates were substantially lower during the second exposure than during the first.

Figure 2 shows mean preratio pausing in the initial token-production segment (the time prior to the first response on the token-production key) as a function of exchange ratio and schedule type for each pigeon (first exposure only). (Due to a programming error, an occasional initial-segment pause was missed for Pigeons 732 and 1855. These data, which accounted for less than 2% of the steady-state analyses presented in Figures 2 through 4, were therefore omitted.) Pausing increased systematically with FR exchange ratio. Pausing under the VR exchange schedules was much less sensitive to changes in ex-

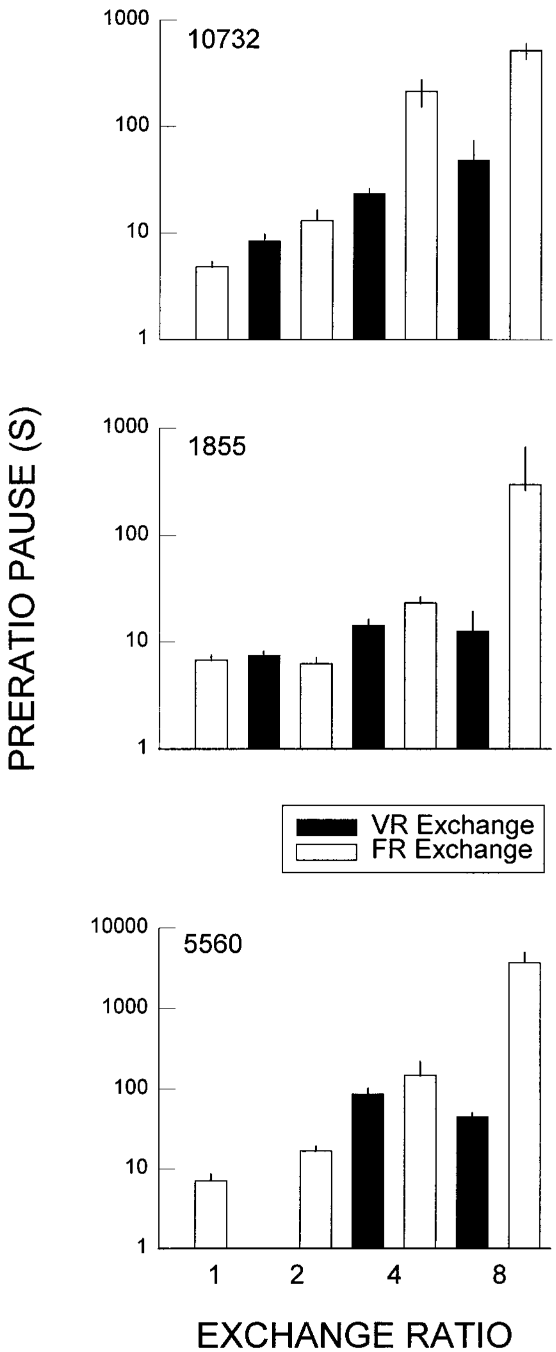

Fig. 2. Mean preratio pausing from initial token-production segment under FR (open bars) and VR (filled bars) exchange schedules. Error bars indicate one standard deviation above the mean. Note individually scaled logarithmic *y* axes.

change ratio, and at the higher exchange ratios was consistently shorter than pausing under comparable FR exchange schedules.

Figure 3 shows mean preratio pausing across successive token-production segments under FR and VR exchange schedules for each pigeon (first exposure only). To facilitate comparison between the FR and VR exchange conditions, only the VR exchange segments that correspond with FR exchange segments are presented. Consistent with the data shown in Figure 2, pausing was longer in the initial token-production segment than in subsequent segments under both schedule types. In most cases, a bivalued pattern emerged: Pausing was longer in the initial token-production segment and shorter and relatively undifferentiated thereafter. The few exceptions to this general pattern occurred at the highest exchange ratio and were characterized by a more gradual decrease in pausing across successive token-production segments.

Figure 4 shows mean local response rate [total segment responses/(total segment time − preratio pause)] across successive token-production segments under FR and VR exchange schedules for each pigeon (first exposure only). Rates were generally lower in the initial token-production segment under both schedule types. In subsequent token-production segments, rates differed with respect to schedule type. Rates under VR exchange conditions were generally high and, beyond the first few token-production segments, were unaffected by position. Rates under FR exchange conditions increased systematically across successive token-production segments, converging with VR rates in the later segments.

Discussion

Consistent with results of prior research on token-reinforced behavior in rats (Malagodi, 1967b) and chimpanzees (Kelleher, 1957b), response rates systematically declined as a function of the FR exchange schedule. These decrements were due largely to extended preratio pausing in the initial token-production segment. Once a token was produced, pausing in subsequent segments was attenuated. This bivalued pattern, with extended pausing in the initial token-production segment giving way to low undifferentiated paus-

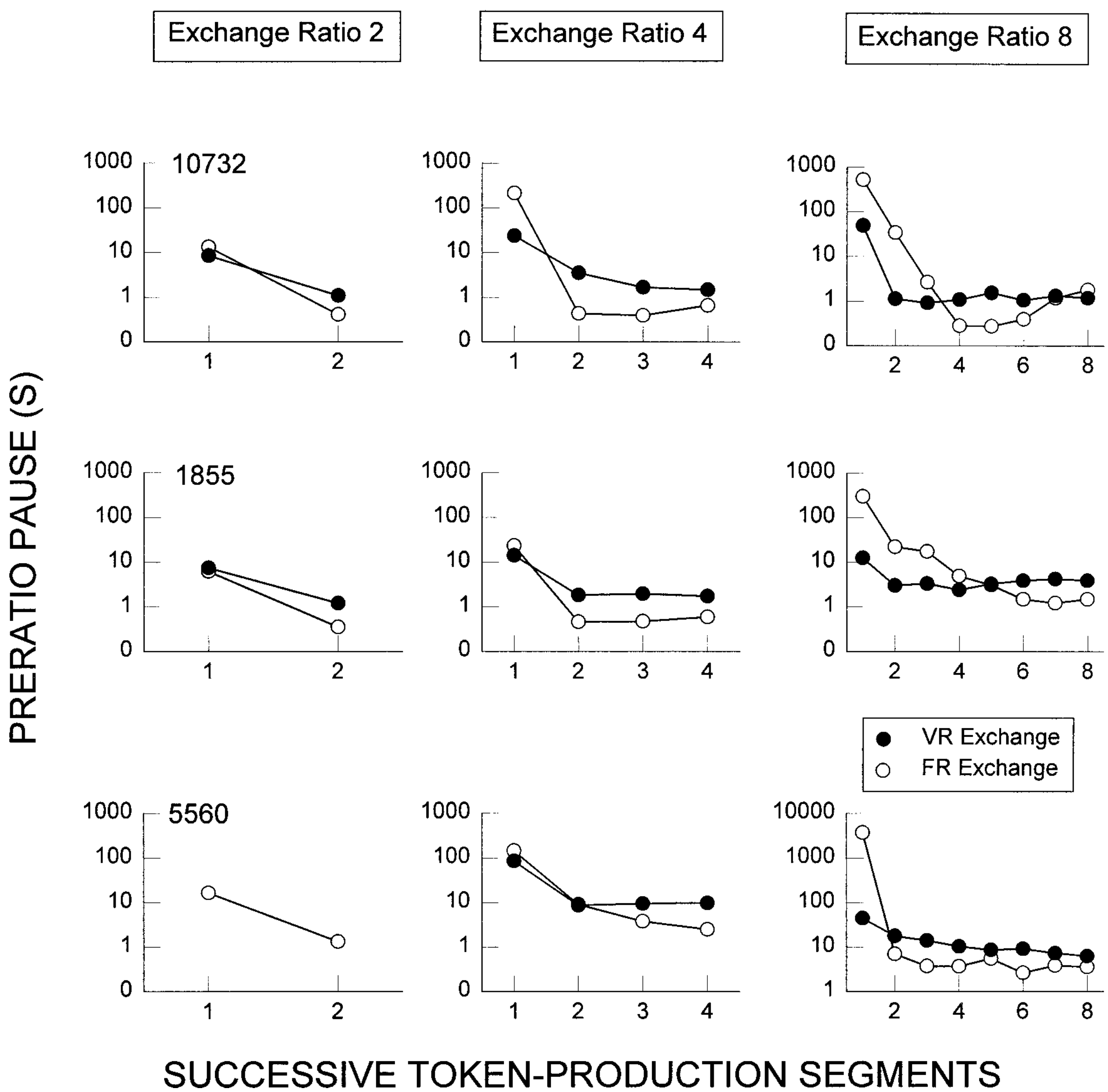

Fig. 3. Mean preratio pausing across successive token-production segments under FR (open symbols) and VR (filled symbols) exchange schedules. Note individually scaled logarithmic *y* axes.

ing in subsequent segments, is also consistent with previous findings with chimpanzees on token-reinforcement schedules (Kelleher, 1958). The extended pausing observed under the FR 8 exchange ratio—ranging from several minutes (Pigeons 10732 and 1855) to frequently in excess of an hour (Pigeon 5560)—is also consistent with Kelleher's findings with chimpanzees under high FR exchange ratios.

At a given exchange ratio, response rates were consistently higher, and preratio pausing consistently shorter, under VR exchange schedules than under comparable FR exchange schedules, despite an equivalent average number of responses per exchange and per food delivery. Such differences as a function of schedule type are also consistent with prior research with second-order token schedules (Webbe & Malagodi, 1978). In the research of Webbe and Malagodi, comparisons of VR and FR exchange schedules were limited to a single value (120 responses per reinforcer); the present results extend the

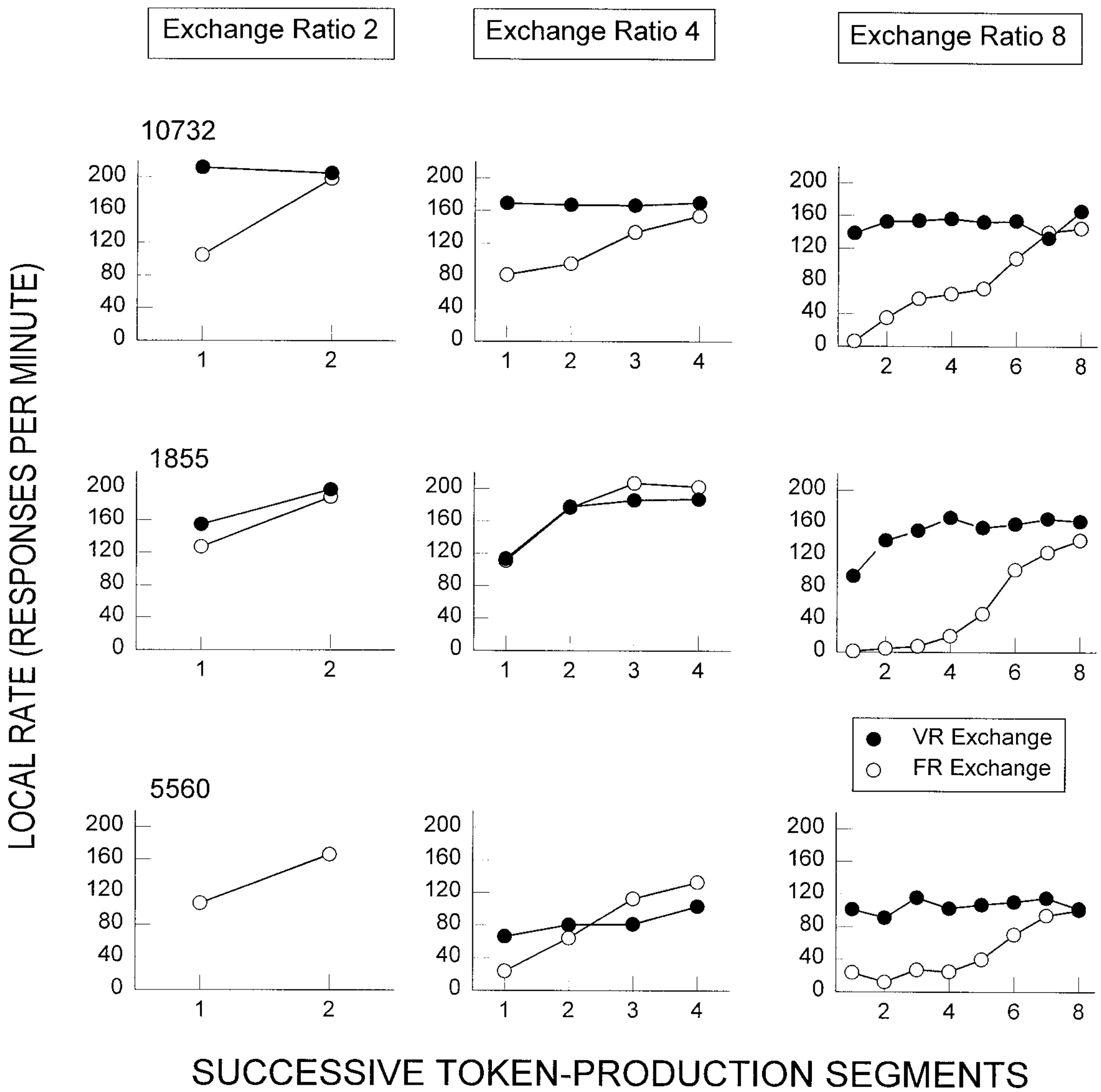

Fig. 4. Mean local response rate across successive token-production segments under FR (open symbols) and VR (filled symbols) exchange schedules.

generality of this effect to a wider range of conditions (from 100 to 400 responses per reinforcer).

The overall pattern of results under FR and VR exchange schedules was similar to that for individual responses under simple FR and VR schedules, which is consistent with the suggestion that first-order schedule performances are conditionable with respect to second-order schedule requirements (Kelleher, 1966; Marr, 1979; Zeiler, 1977). As applied to token-reinforcement schedules, performance generated under the first-order (token production) sequence is to the second-order (exchange) schedule as an individual lever press or key peck is to a simple schedule. If such units exist at the level of the second-order (exchange) schedule, one would expect correspondences between exchange-schedule performances and those maintained under simple FR and VR schedules.

There are several aspects of the present results that are consistent with such an analysis. First, the direct relation between FR schedule value and preratio pausing in the initial component is in accord with the results of numerous studies with simple FR schedules (Baron & Herpolsheimer, 1999; Felton & Lyon, 1966; Ferster & Skinner, 1957; Mazur, 1983; Powell, 1968; Zeiler, 1999). Second, although the evidence is less abundant than for FR schedules, the greater sensitivity of preratio pausing to FR than to VR exchange value is also generally consistent with effects reported with simple VR schedules and individual responses (Mazur, 1983).

Third, although most of the response-rate changes were due to preratio pausing in the initial segment, there were also schedule-related differences in the local response rates aross successive segments. Response rates increased across successive token-production segments under both schedule types at the higher exchange ratios, but were more sensitive to ratio position under FR than under VR schedules. Late-position rates were comparable under the two schedule types, but reached asymptote more quickly under the VR exchange schedules (normally within the first few segments). These effects are also generally consistent with those reported under simple ratio schedules (Kintsch, 1965; Mazur, 1983) and under other second-order schedules (Davison, 1969).

Together, these exchange-schedule effects are consistent with a second-order schedule interpretation that treats token-production performance as a conditionable unit. Such an interpretation is also predicated, however, on the integrity of the within-segment token-production sequences, that is, the degree to which within-segment patterns resemble their simple-schedule counterparts (Marr, 1979; Zeiler, 1977). Because token-production performance was not analyzed directly, however, evidence bearing on the unitary properties of token-production responding is limited. In Experiment 2, different token-production schedules were compared to examine more closely the role of the token-production schedule.

EXPERIMENT 2

The results of Experiment 1 confirm and extend the principal finding from prior research on simple and second-order ratio schedules: Response rates and patterns varied systematically as a function of ratio size and schedule type. Experiment 2 sought to extend these findings while examining more closely the contributions of the first-order (token-production) schedule. As in Experiment 1, exchange ratio and schedule type were varied across conditions. Unlike Experiment 1, pigeons were exposed to a VR token-production schedule with FR exchange schedules in addition to an FR token-production schedule with VR exchange schedules. This permitted a closer analysis of the correspondence between token-production sequences and simple FR and VR schedules, which is important in assessing the unitary properties of token-reinforced behavior.

To provide within-session comparisons of performance under the two schedule types, a multiple schedule was used in which both schedule types alternated several times per session, each in the presence of a distinct stimulus. In addition, the average response requirements per token, per exchange period, and per food delivery were held constant across the two schedule types. For example, with an exchange ratio of 4, an average of 50 responses per token delivery and a fixed 200 responses per exchange were required in the FR exchange component (FR 4 [VR 50]), whereas a fixed 50 responses per token delivery and an average of 200 responses per exchange were required in the VR exchange component (VR 4 [FR 50]). The influence of the VR token-production schedule could be assessed by comparing performance under the FR *x* (VR 50) conditions in this experiment with the FR exchange conditions from Experiment 1 (e.g., FR *x* [FR 50]). At the same time, comparing performance under the VR *x* (FR 50) conditions here with the earlier VR exchange conditions permits an assessment of the reliability of the effects obtained in a single-schedule arrangement by demonstrating them in a multiple-schedule arrangement.

METHOD

Subjects

Four adult male White Carneau pigeons with brief conditioning histories served as subjects. Housing, deprivation, and feeding conditions were the same as in Experiment 1.

Table 2

Experiment 2. The sequence of conditions (exchange-schedule values are noted) and the number of sessions (in parentheses) conducted under each condition.

Pigeon			
10756	10727	10970	3356
FR 1 FR 1 (25)	FR 1 FR 1 (49)	FR 1 FR 1 (23)	FR 1 FR 1 (42)
FR 2 VR 2 (39)	FR 2 VR 2 (29)	FR 2 VR 2 (27)	FR 2 VR 2 (21)
FR 4 VR 4 (38)	FR 4 VR 4 (38)	FR 4 VR 4 (28)	FR 4 VR 4 (45)
FR 8 VR 8 (22)	FR 8 VR 8 (26)	FR 8 VR 8 (28)	FR 8 VR 8 (20)
FR 4 VR 4 (26)	FR 4 VR 4 (21)	FR 4 VR 4 (20)	FR 4 VR 4 (29)
FR 2 VR 2 (30)	FR 8 VR 8 (24)	FR 2 VR 2 (32)	
FR 8 VR 8 (28)	FR 8 VR 8 (30)[a]	FR 8 VR 8 (29)[a]	
FR 8 VR 8 (20)[a]			

[a] In these conditions, the key colors associated with multiple-schedule components were reversed.

Apparatus

The experimental chamber was similar to the one used in Experiment 1. The only major difference was that the experimental space was smaller, measuring 35 cm high, 35 cm wide, and 31 cm long. All other details of programming and data collection were the same as in the first experiment.

Procedure

The token-production and exchange training procedure was similar to analogous conditions in Experiment 1, except that the token-production key (either left or right side key) was transilluminated green or yellow with $p = .5$. The two colors were used to establish responding in the presence of the stimuli correlated with the components of the multiple schedule.

When token-production and exchange responding had been established (approximately 14 sessions), the pigeons were exposed to a two-component multiple schedule with each component containing a second-order schedule of token reinforcement. In one component, a VR token-production schedule operated within the context of an FR exchange schedule (FR x [VR 50]). In the other component, an FR token-production schedule operated within the context of a VR exchange schedule (VR x [FR 50]). Thus, tokens were produced according to VR 50 and FR 50 schedules, and were exchanged according to FR and VR schedules.

The green and yellow keylights correlated with respective components of the token-production schedules were counterbalanced across pigeons. For Pigeons 10756 and 10727, yellow was arbitrarily assigned to the VR x (FR 50) component and green to the FR x (VR 50) component, with these assignments reversed for Pigeons 10970 and 3356. The location of the token-production key (left or right side key) also varied across pigeons: left key for Pigeons 10756, 10727, and 10970 and right key for Pigeon 3356.

The exchange ratio was varied systematically across conditions, from 1 to 8. Hence, in the FR exchange conditions, an average of 50 responses produced one token, which could be exchanged for food after a fixed number of tokens had been earned. In the VR exchange conditions, a fixed 50 responses produced one token, which could be exchanged for food after a variable number of tokens had been earned. As in Experiment 1, the VR schedule values were drawn without replacement from a rectangular distribution ranging from 1 to $2n - 1$, with n set equal to the mean VR schedule value.

Table 2 shows the sequence of conditions and the number of sessions per condition for each pigeon. Experimental conditions were initially presented in ascending order of ratio size. Subsequently, various exchange-schedule manipulations were replicated, and a color-reversal condition was conducted, during which the key colors correlated with the FR x (VR 50) and VR x (FR 50) schedule components were reversed. Pigeon 3356 died following the replication of the VR 4 FR 4 exchange condition. Sessions were conducted daily, and the stability criteria were the same as in Experiment 1.

Each component of the multiple schedule was presented twice during a session. To min-

Table 3

Experiment 2. Response requirements under token-production and exchange schedules within multiple-schedule components.

Schedule component type[a]	Responses to produce: a token	Responses to produce: an exchange period	Number of exchange cycles[b]
FR 2 (VR 50)	1 to 99	100	8
VR 2 (FR 50)	50	50 to 150	Undetermined
FR 4 (VR 50)	1 to 99	200	4
VR 4 (FR 50)	50	50 to 350	Undetermined
FR 8 (VR 50)	1 to 99	400	2
VR 8 (FR 50)	50	50 to 750	Undetermined

[a] The token-exchange schedule is listed before the token-production schedule.
[b] An exchange cycle refers to an exchange sequence within a multiple-schedule component, and cycle values are based on 16 tokens per component.

imize strict alternation of component presentation, the first and third component types were determined with $p = .5$, and the second and fourth component types were the complements of the first and third, respectively. Component presentations were separated by a 30-s intercomponent interval, during which the chamber was dark and responding had no programmed consequences.

Table 3 shows the response requirements for token production and exchange within components of the multiple schedule. To equate overall number of responses per reinforcer across components, 800 responses were required per component, with components ending when 16 tokens had been exchanged. In each component of the multiple schedule, each token was exchangeable for 1.5-s access to food. Thus, across the four components, 3,200 responses were required per session for a total of 96 s of access to food. All VR production and exchange requirements were determined before a given schedule component began. To hold constant the component-wide response requirement for the VR 50 token-production schedule, the final ratio values were repicked as necessary to sum the ratio requirements to 800. Similarly, to hold constant the number of tokens available during the VR exchange-schedule components, the final exchange ratios were repicked as necessary to sum the number of tokens to 16.

Results

All results are based on the final five sessions of each condition. Figure 5 shows overall response rates as a function of exchange ratio and schedule type (FR or VR) for each pigeon. Under the FR 1 exchange schedule, response rates during the VR 50 and FR 50 token-production schedules were comparable for all pigeons. In subsequent conditions, increases in the FR exchange schedules systematically decreased response rates for each pigeon. By contrast, response rates were much less affected by ratio size under VR exchange schedules. At the highest two exchange ratios, the VR exchange schedules maintained consistently higher response rates than did the FR exchange schedules. With a few exceptions (VR 2 exchange schedule for Pigeon 10970 and VR 4 exchange schedule for Pigeon 10756), response rates from replicated conditions corresponded well to original exposures.

Figure 6 shows mean preratio pausing in the initial token-production segments as a function of exchange ratio and schedule type for each pigeon (first exposure only). Pausing increased systematically with FR exchange ratio. Pausing also increased as the VR exchange ratio increased, but the magnitude of this effect was smaller than under the FR exchange ratios. At the highest two exchange ratios, the FR exchange schedule produced substantially greater pausing than did the VR exchange schedule.

Figure 7 shows mean preratio pausing across successive token-production segments under FR and VR exchange schedules for each pigeon (first exposure only). To facilitate comparison between the VR and FR exchange conditions, only the VR exchange seg-

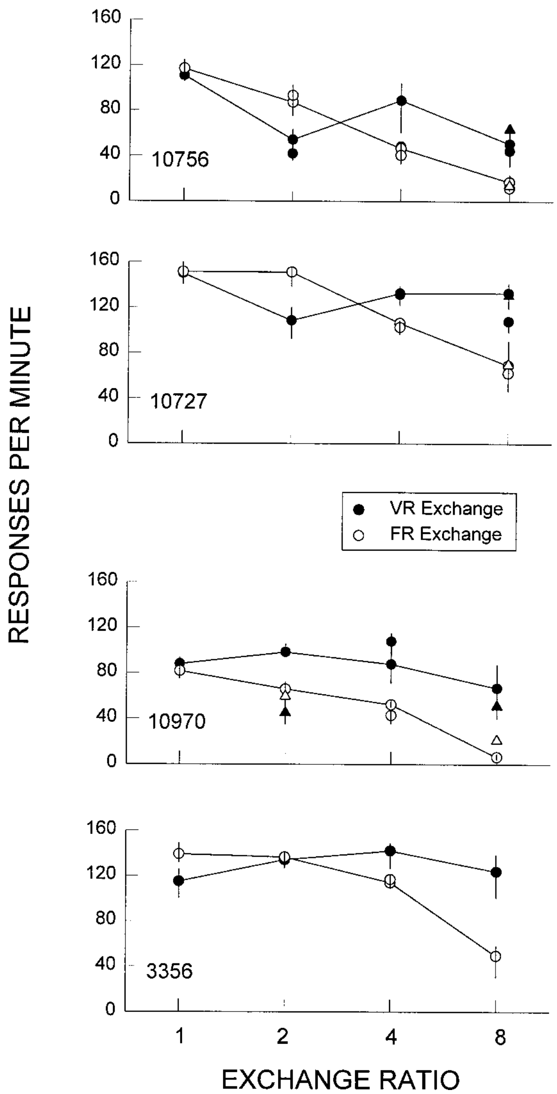

Fig. 5. Mean number of responses per minute as a function of FR (open symbols) and VR (filled symbols) exchange ratio. Connected points represent data from original exposures, unconnected points represent data from second exposures, and triangles represent data from color-reversal replications. Error bars indicate the range of values contributing to the condition mean.

ments that correspond with FR exchange segments are presented. For all pigeons across all conditions, preratio pausing was longer during the initial token-production segments than in subsequent segments. Following the initial segment, pause duration decreased sharply and remained nearly equal across both FR and VR exchange conditions. Although not depicted in the figure, mean pausing during segments of the VR exchange schedules beyond those presented were similar to those depicted in the final segment (e.g., for the VR 4 exchange, the pause during Segments 5 through 7 was similar to that of Segment 4).

Figure 8 shows mean local response rate, defined as in Experiment 1, across successive token-production segments for each pigeon (first exposure only). For all pigeons under both exchange-schedule types, local rates were typically lower in the initial segment than in subsequent segments, especially at the higher exchange ratios. The variation in response rates in subsequent segments was related to exchange-schedule type. Under the VR exchange schedule, rates were high and relatively undifferentiated following the initial few segments. Under the FR exchange schedule, rates began low but increased monotonically across successive token-production segments, eventually converging with VR exchange rates in the terminal segments.

Figure 9 shows cumulative response records for Pigeons 10756 and 3356 from a representative session selected from the final five sessions of the FR 8 VR 8 exchange condition. (To save space, the records for Pigeons 10756 and 3356 were selected as representative of those for Pigeons 10970 and 10727, respectively.) Response rates were high and steady for both pigeons under the VR 8 (FR 50) schedule, as indicated by the relatively steep slopes of the records. For Pigeon 10756, response patterns were bivalued: Responding occurred at a steady rate prior to token deliveries, and pausing occurred following token deliveries and exchange periods. This pause–run pattern occurred to a lesser degree for Pigeon 3356. Under the FR 8 (VR 50) schedule, the performance of both pigeons was characterized by more extensive preratio pausing (sometimes exceeding 30 min for Pigeon 10756). The portions of the record that precede and follow the first token delivery in the record of Pigeon 10756 are characterized by brief response bursts followed by brief pausing, generating a "grainy" record. After several tokens were delivered, the slope of the record changes from relatively shallow to steep, indicating that response rates gradually increased and remained steady. This grainy response pattern and gradual change in rate occurred to a lesser extent for Pigeon 3356,

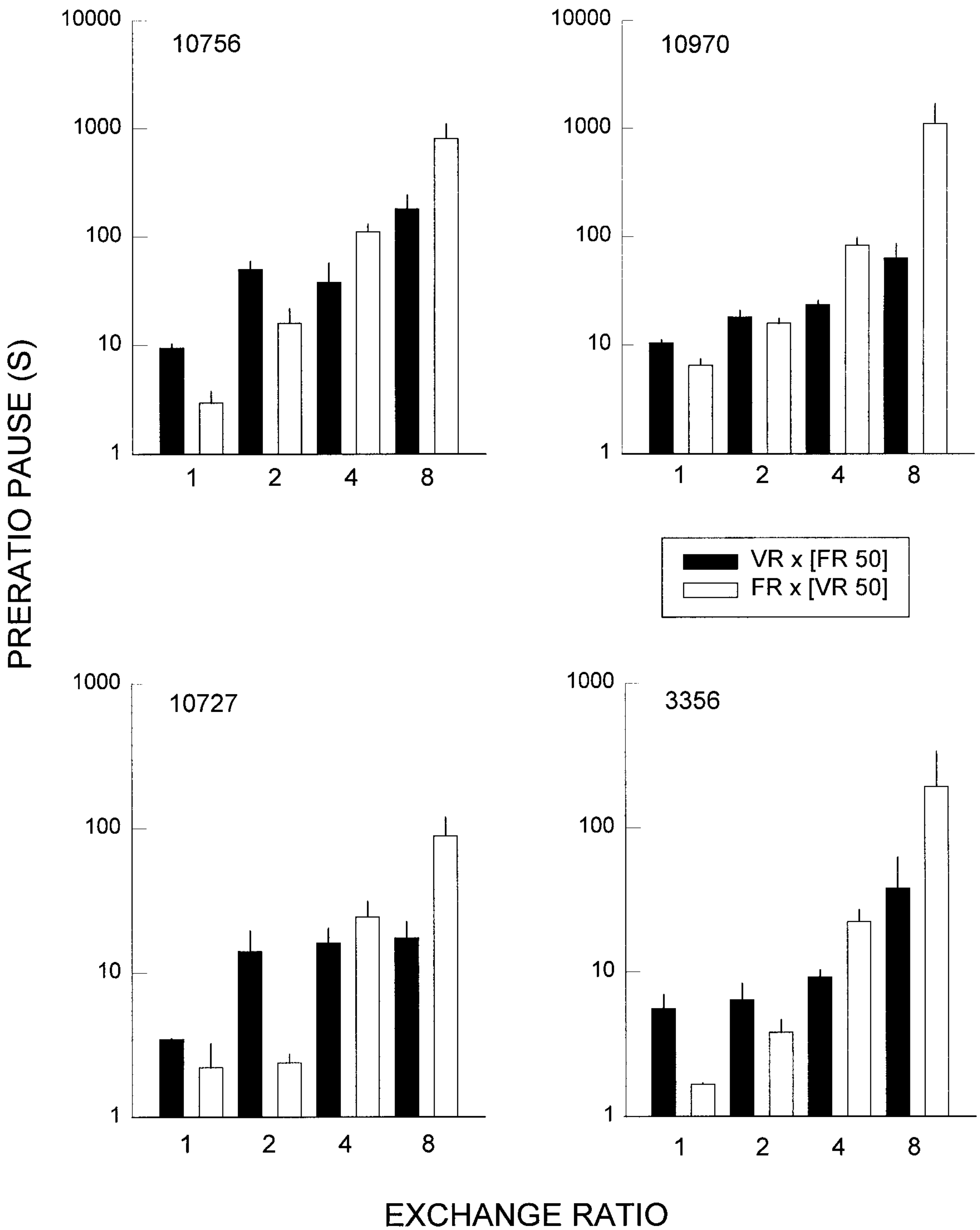

Fig. 6. Mean preratio pausing from the initial token-production segment under FR (open bars) and VR (filled bars) exchange schedules. Error bars indicate one standard deviation above the mean. Note individually scaled logarithmic *y* axes.

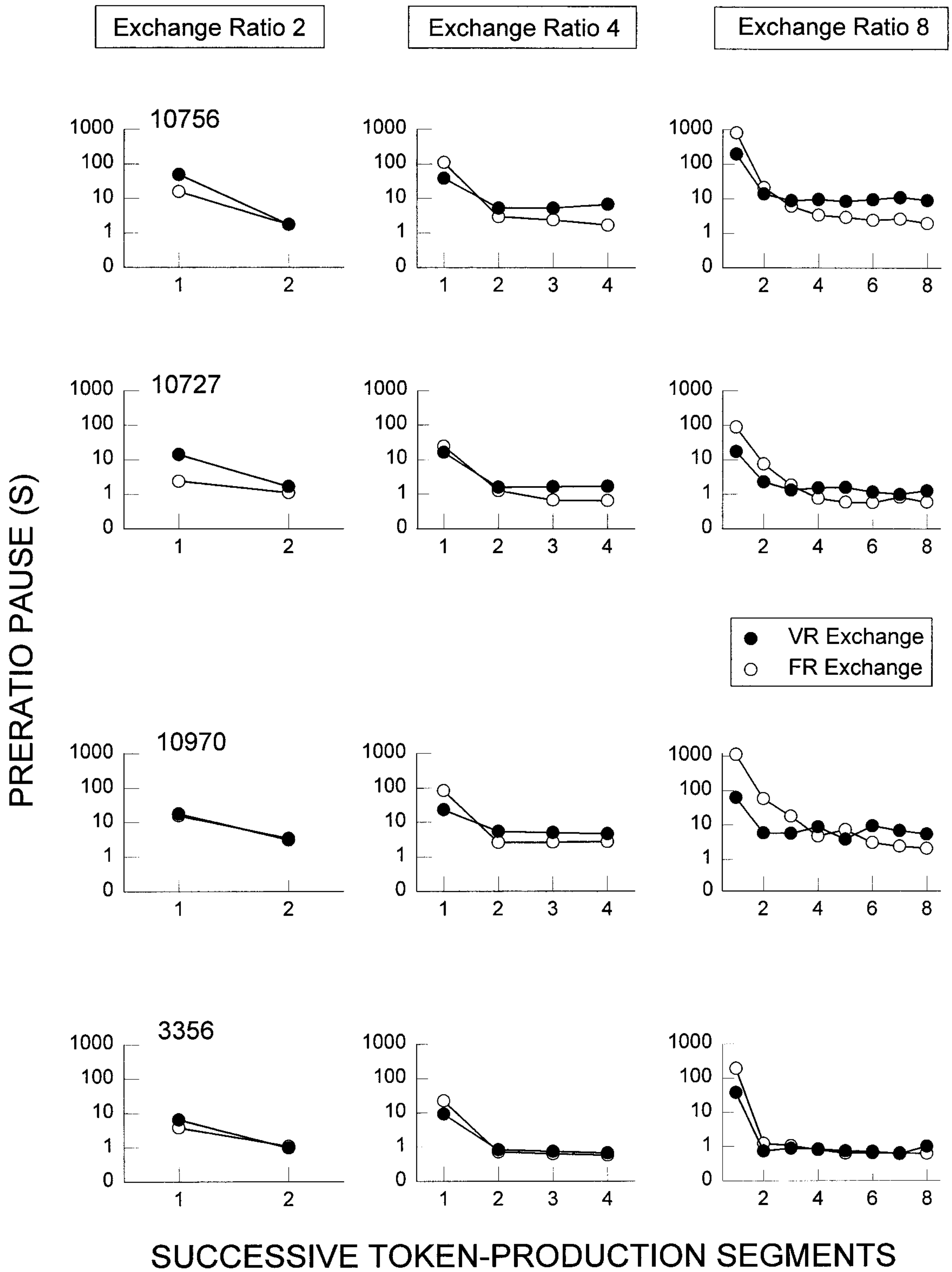

Fig. 7. Mean preratio pausing across successive token-production segments under FR (open symbols) and VR (filled symbols) exchange schedules. Note logarithmic y axes.

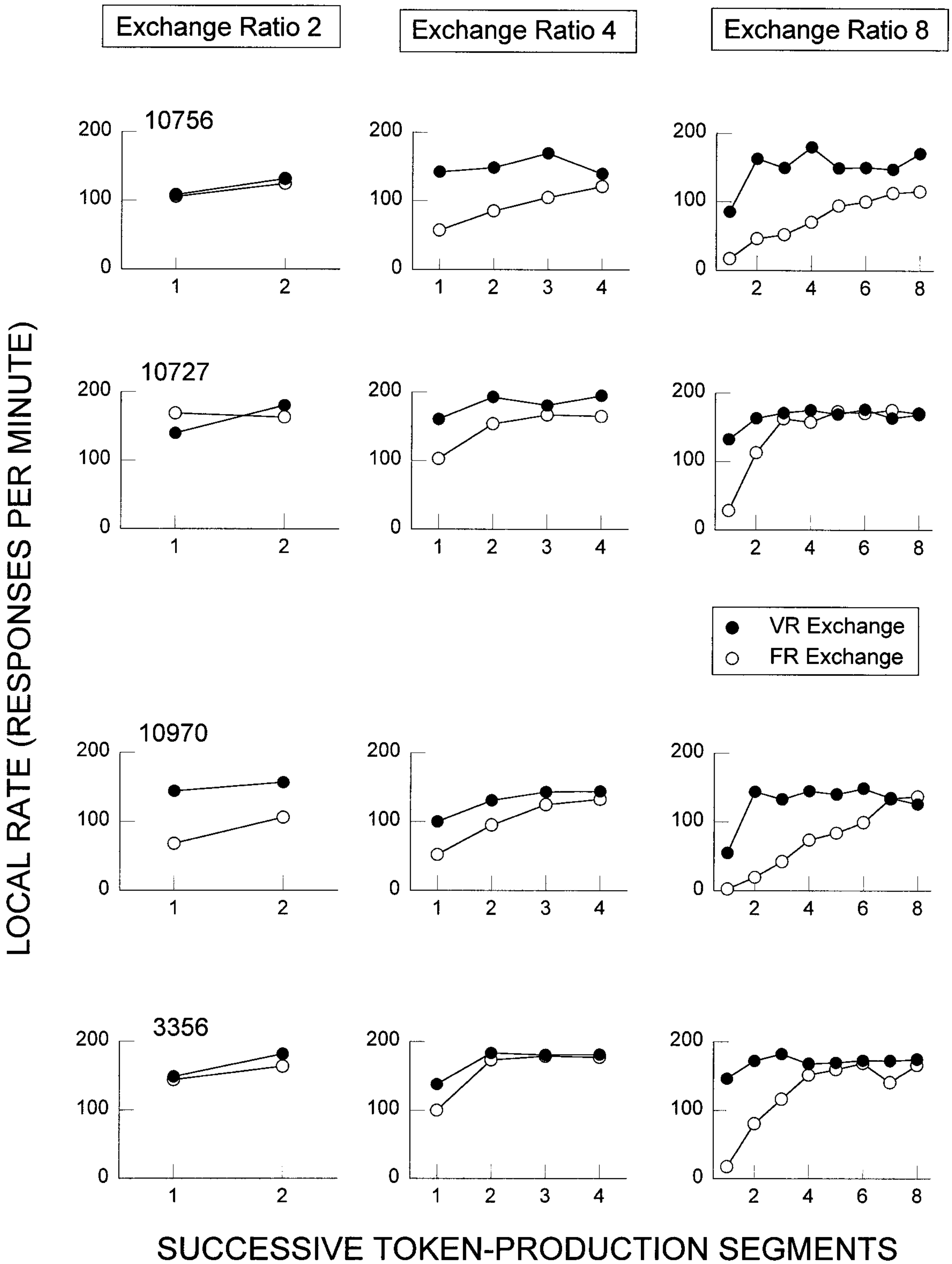

Fig. 8. Mean local response rate (run rate) across successive token-production segments under FR (open symbols) and VR (filled symbols) exchange schedules.

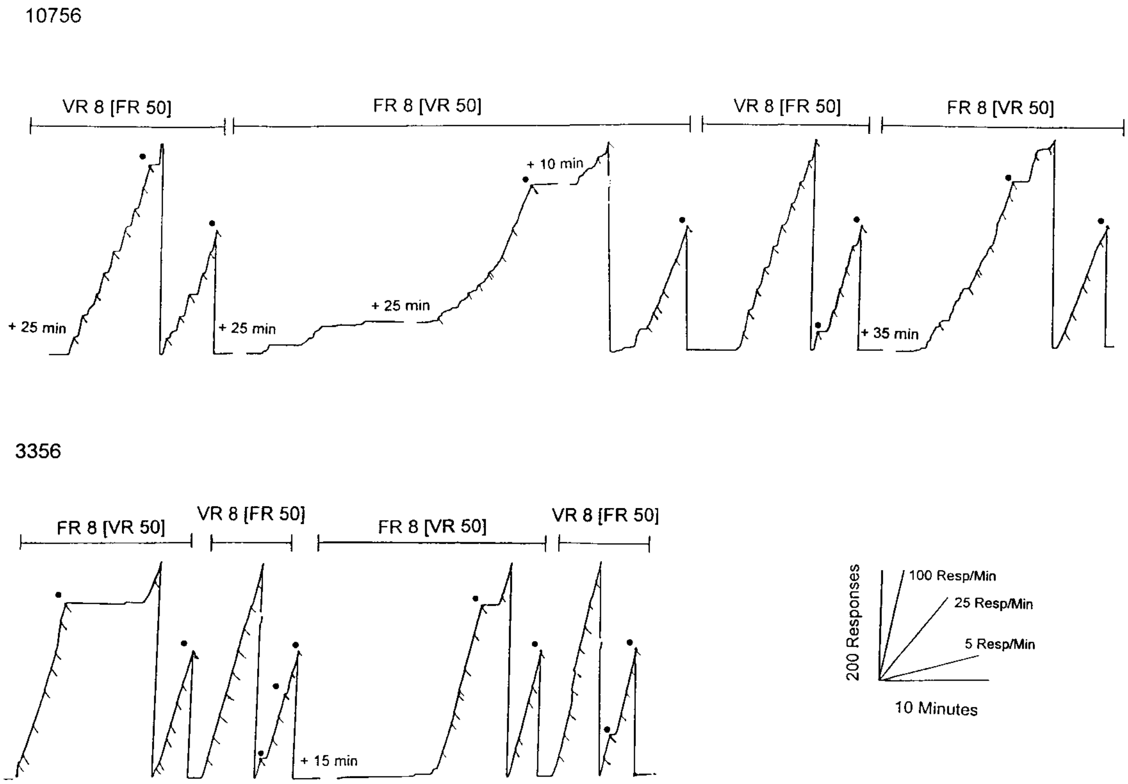

Fig. 9. Representative cumulative response records from one of the final five sessions under the FR 8 VR 8 exchange condition (first exposure) for Pigeons 10756 and 3356. Four multiple-schedule components are shown, and each is labeled above the brackets: FR 8 (VR 50) denotes the FR 8 exchange schedule and VR 8 (FR 50) the VR 8 exchange schedule. Deflections of the response pen (pips) denote token presentations and, if accompanied by a filled circle, exchange periods. Breaks in the records show where portions have been removed; responding was absent for the period noted above the break. The response pen reset both when the vertical limit of the record was reached and when components changed. The cumulative recorder did not operate during the blackout periods between components.

for which the slopes of the records following the first token delivery under FR 8 (VR 50) appear roughly similar to those under VR 8 (FR 50).

Discussion

The pattern of results was in close agreement with that of Experiment 1. For most pigeons under most conditions, VR exchange schedules produced higher response rates than FR exchange schedules, and these schedule-related differences increased with increases in ratio size. As in Experiment 1, the differences in overall response rates under FR and VR schedules were due primarily to extended preratio pausing and to lower local response rates in the initial token-production schedule segments.

The occasional occurrence of an exchange period following production of a single token may have contributed to the relatively high and uniform response rates obtained under even the most stringent VR exchange values. Past research with simple schedules has shown that the smallest ratio in a VR distribution is an important determinant of response rates and patterns on VR schedules (Blakely & Schlinger, 1988; for analogous results with concurrent schedules, see Duncan & Fantino, 1970; Fantino, 1967; Field, Tonneau, Ahearn, & Hineline, 1996). The only report of sustained responding under simple VR schedules with response requirements approaching the maximum values used here (Ferster & Skinner, 1957) also used a VR distribution with many small values.

Previous comparisons of VR and FR exchange schedules were conducted using only

FR production schedules. The results pertaining to the FR *x* (VR 50) schedule, therefore, demonstrate exchange-schedule effects with a novel token-production schedule and extend the generality of previous findings (e.g., Webbe & Malagodi, 1978). The VR and FR token-production schedules produced schedule-typical differences in local response patterning for 2 of the 4 pigeons (represented by the top panel in Figure 9). Such patterning, however, also depended on proximity to the exchange period. Late-segment rates were higher and pauses were shorter, more characteristic of small-ratio performance, than early-segment rates and patterns, more characteristic of performance under moderate to large ratios. In other words, the token-production schedule interacted with the second-order exchange schedule to determine within-segment response patterning. For the other 2 pigeons (represented by the bottom panel in Figure 9), any control by the token-production schedule was obscured by interactions with the tokens as segment-correlated stimuli. Response rates were higher and more uniform across segments beyond the first, in that discriminative control by the tokens was more binary than graded. Perhaps if the token-production ratios had been larger, performances of these 2 pigeons would have been more in line with those of the other 2 pigeons. In any event, a stronger basis for assessing the correspondence between token-production responding and individual responses awaits additional research involving manipulations of token-schedule value. Such work is currently under way in our laboratory.

GENERAL DISCUSSION

The main findings of these experiments are consistent with previous research on token-reinforcement schedules in demonstrating that token-exchange schedules control token-reinforced behavior (e.g., Kelleher, 1957a, 1957b; Malagodi, 1967b, 1967d; Webbe & Malagodi, 1978). Specifically, the present results extend Webbe and Malagodi's finding that response rates and patterns assume either FR- or VR-like properties, depending on the second-order exchange schedule. In both experiments reported here, response rates were consistently higher, and pausing was consistently shorter, under VR exchange schedules than under comparable FR exchange schedules, especially at the larger ratio values.

The results are also in general agreement with those obtained under non-token-based sequence schedules with ratio components, including extended chained schedules (Findley, 1962; Jwaideh, 1973) and second-order schedules of brief stimulus presentation (Findley & Brady, 1965; Lee & Gollub, 1971; Stubbs, 1971, Experiment 3). Procedurally, the present procedures are perhaps most closely aligned with added-stimulus schedules (Ferster & Skinner, 1957; Zimmerman & Ferster, 1964), a kind of second-order schedule in which completion of successive component schedules produces stimuli that gradually accumulate until the delivery of primary reinforcement.

In Zimmerman and Ferster's (1964) experiment, pigeons pecked at one key on a variable-interval (VI) schedule in view of a voltmeter. Successive VI completions moved the voltmeter needle a fixed distance, and when the maximum reading was reached, pecks on a second key produced food. As with token-reinforcement schedules, the number of needle deflections was directly related to the number of food deliveries. Responding was generally characterized by a bivalued pattern, in which low response rates in the initial VI segments gave way to higher rates as the maximum meter reading was approached. Increasing the number of deflections required for the maximum reading from 10 to 20 lowered the overall response rate, mainly by further weakening responding in the initial segments. These results are in general agreement with those obtained in the present experiments under FR exchange schedules. The weak responding in the initial segments is consistent with the prolonged pausing seen in early token-production segments, and the positively accelerating rate of responding as the maximum meter reading was approached is consistent with the across-segment response rates seen as the exchange period was approached. In addition, the effects on overall response rate of increasing the number of constituent VI schedules paralleled those of increasing the exchange ratio in the present experiments.

Such sensitivity to exchange-schedule variables is consistent with a second-order schedule interpretation, according to which first-order schedule performances are conditionable with respect to second-order schedule requirements. As Marr (1979) has noted, however, unitary properties of second-order schedule performance are clearest when correspondence with simple schedules can be demonstrated both at the level of within-segment behavior (i.e., the pattern of responding between stimulus presentations) and at the level of across-segment behavior (i.e., the pattern of responding across sequences of schedule components terminating in food).

The schedule-related differences in rates and patterns as a function of exchange-schedule variables presented above are consistent with the second criterion. Because within-segment (token-production) schedule variables were examined at only a single value, however, evidence concerning the first criterion is more limited than that for exchange-schedule variables, and consists mainly of the cumulative records shown in Figure 9. Although within-segment patterns were often appropriate to the token-production schedule (supporting a view of token-production sequences as unitary responses), interactions with the exchange schedule and with stimulus variables obscured orderly relations at the within-segment level.

Such interactions are especially likely under added-stimulus schedules in which stimuli are temporally correlated with reinforcement. Unlike second-order schedules with briefly presented stimuli, the segment-correlated stimuli in added-stimulus schedules remain present throughout the sequence of components terminating in food. Moreover, in added-stimulus schedules, the number and arrangement of stimuli are correlated not only with proximity to reinforcement but with amount of reinforcement. This arrangement of stimuli is likely to enhance the discriminative functions of the added stimuli. In the Zimmerman and Ferster (1964) study described earlier, responding under the schedule with added stimuli (meter readings) was compared to that under a tandem schedule, in which completion of component schedules produced no change in the meter. Across-segment response rates were more sensitive to ordinal position in the ratio under conditions with added stimuli than under conditions without added stimuli, suggesting heightened discriminative control by segment-correlated stimuli (see also Ferster & Skinner, 1957, for analogous effects with fixed-interval schedules).

Such temporal-correlative relations between stimuli and food arranged within added-stimulus schedules may also give rise to behavior elicited by the segment-correlated stimuli. When the segment-correlated stimuli are tokens, such behavior can take the form of orienting to, and contact with, the tokens. Indeed, such token-directed behavior has been regarded as a critical feature of token-reinforcement procedures (Boakes et al., 1978). By this view, the tokens, by virtue of consistent pairings with food, acquire conditional stimulus (CS) functions, which compete with operant behavior maintained by token production and exchange. Similarly, the stimulus lights used as tokens in the present study may have acquired CS functions, eliciting responding on the pattern of sign tracking (Schwartz & Gamzu, 1977). Although our pigeons were not directly observed during experimental sessions, pigeons in Jackson and Hackenberg's (1996) study did occasionally orient toward and peck at the stimulus lights, an observation that has been confirmed in other token-reinforcement studies in our laboratory.

This is generally consistent with an elicitation view, but there are procedural reasons to suspect that nonmanipulable tokens such as stimulus lights would engender less token-directed behavior than do manipulable tokens in more conventional token-reinforcement procedures. Although both procedures arrange a similar temporal relation between tokens and food, only in procedures involving manipulable tokens is explicit handling of the token required as part of the exchange response (token deposit). This not only guarantees close temporal contiguity between tokens and food availability but it also differentially reinforces contact with the tokens as part of the sequence of responses terminating in food delivery. By contrast, the stimulus lights used as tokens in our procedures were presented and exchanged without an explicit handling requirement. Token-directed behavior (e.g., orientation, pecking) thus was permitted but was not required. By decoupling the handling requirement from the token–food relation, procedures like those used here may be useful in separating behavior evoked by token–food pairings from behavior maintained by token production. Such procedures may provide a bridge to laboratory and applied research with humans, for which there is ample precedent for regarding as tokens nonmanipulable stimuli (e.g., points, check marks on a chart) exchangeable for other reinforcers.

The general comparability of the present results with those of previous token-reinforcement studies suggests that token-based schedules of the added-stimulus variety share important functional properties with more conventional token-based schedules involving manipulable stimuli. But it is still unclear whether, or to what extent, the stimulus lights used as tokens in the present study are functionally equivalent to marbles, poker chips, and other manipulable tokens. As stimuli standing in consistent temporal relation to reinforcement, tokens (both manipulable and nonmanipulable) unquestionably serve multiple functions. The precise functions of tokens (discriminative, reinforcing, eliciting) will depend on the specific temporal-correlative relations among responding, tokens, and reinforcement. Additional research is needed to determine more precisely the functional role of the stimulus lights, including comparisons to conditions without added stimuli.

In closing, it is worth noting the implications of the present research for behavioral economics. Over the past 30 years, both behavior analysts and economists have noted the potential benefits of collaborative research using token-reinforcement systems (Castro & Weingarten, 1970; Kagel, 1972; Kagel & Winkler, 1972; Lea, 1978; Lea, Tarpy, & Webley, 1987; Winkler, 1980). Some experiments on economic variables such as income and spending have been conducted with clients in token-based treatment settings, but therapeutic goals and ethical issues often limit the range of experimental contingencies that may be implemented (e.g., Winkler, 1971, 1980). For this reason, conducting experimental research using analogues of token economies and nonhuman organisms affords many advantages (Castro & Weingarten, 1970; Kagel, 1972; Kagel & Winkler, 1972). Such arrangements could enhance behavioral economic research by providing opportunities to systematically examine economic variables (e.g., income and price) in ways that are more commensurate to those studied with humans. In this way, token-reinforcement schedules may begin to realize their potential, first noted by Kagel and Winkler (1972), to weave basic schedule research into a broader economic framework.

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